U.S. NUCLEAR REGULATORY COMMISSION

STANDARD REVIEW PLAN

OFFICE OF NUCLEAR REACTOR REGULATION

3.5.3 BARRIER DESIGN PROCEDURES

REVIEW RESPONSIBILITIES

Primary Structural Engineering Branch (SEB)

Secondary None

I. AREAS OF REVIEW

The following areas relating to procedures utilized in the design of seismic Category I structures, shields, and barriers to withstand the effects of missile impact are reviewed.

1. Procedures utilized for the prediction of local damage in the impacted area. This includes estimation of the depth of penetration and, in case of concrete barriers, the potential for generation of secondary missiles by spalling or scabbing effects.

2. Procedures utilized for the prediction of the overall response of the barrier or portions thereof due to the missile impact. This includes assumptions on acceptable ductility ratios where elasto-plastic behavior is relied upon, and procedures for estimation of forces, moments, and shears induced in the barrier by the impact force of the missile.

3. Accident Evaluation Branch (AEB) reviews the adequacy of missiles' parameters cited in support of the applicant's conclusions concerning their suitability for the plant as part of its primary review responsibility for SRP Section 3.5.1. Structural Engineering Branch reviews the parameters reviewed by the (AEB) for consideration as an integral part of structural analysis.

II. ACCEPTANCE CRITERIA

SEB accepts the design of structures, shields, and barriers that must withstand the effects of environmental and natural phenomena if the relevant requirements of General Design Criteria 2 (Ref. 1) and 4 (Ref. 2) are met. The relevant requirements of General Design Criteria 2 and 4 are as follows:

A. General Design Criterion 2 as it relates to structures, systems, and components, capability to withstand, without loss of safety functions, the effects of tornadoes and the appropriate combinations of the effects of normal and accident conditions with the effects of the natural phenomena.

B. General Design Criterion 4 as it relates to structures, systems, and components being appropriately protected against dynamic effects, including the effects of missiles, pipe whipping, and discharging fluids that may result from equipment failures and from events and conditions outside the nuclear power unit.

Specific criteria necessary to meet the relevant requirements of General Design Criteria 2 and 4 are as follows:

1. For Local Damage Prediction

   a. In Concrete

      Sufficient thickness of concrete should be provided to prevent perforation, spalling, or scabbing of the barriers in the event of missile impact.

      Several empirical equations, such as the modified NDRC formula (Ref. 3) are available to estimate missile penetration into concrete. These equations should be used to determine the required barrier thicknesses. Thicknesses resulting from such calculations should in no case be less than those listed in Table 1, which thicknesses are necessary to protect against tornado missiles.

      The tornado missile spectrum for which Table 1 concrete requirements are adequate is shown in Table 2. Tornado missiles and other types of missiles are specified in accordance with SRP Section 3.5.1.

      Barrier thicknesses less than those listed in Table 1 may be used provided that sufficient justification including test data are presented to support them, in which case they will be reviewed on a case-by-case basis.

      For turbine missile barriers, penetration and scabbing predictions should be based on empirical equations such as the modified NDRC formula (Ref. 3) or the results of a valid test program.

   b. In Steel

      The results of test conducted by the Stanford Research Institute on the penetration of missiles into steel plates are summarized by W. B. Cottrell and A. W. Savolainen in "U. S. Reactor Containment Technology" (Ref. 4). The equations presented in Reference 4 are acceptable. Other equations such as the Ballistic Research Laboratory formula described in Reference 5 may be used provided the results are either comparable to those referenced above, or are validated by penetration tests.

c. In Composite Sections

For composite or multi-element missile barriers, procedures for prediction of local damage are acceptable if the residual velocity of the missile perforating the first element is considered as the striking velocity for the next element. For determining this residual velocity, the equations presented by Recht and Ipson (Ref. 6) are acceptable when the first barrier of a multi-element missile barrier is steel. When the first barrier is concrete, procedures are reviewed on a case-by-case basis.

2. For Overall Damage Prediction

The response of a structure or barrier to missile impact depends largely on the location of impact (e.g., midspan of a slab or near a support), on the dynamic properties of the target and missile, and on the kinetic energy of the missile. In general, the assumption of plastic collisions is acceptable, where all of the missile initial momentum is transferred to the target and only a portion of its kinetic energy is absorbed as strain energy within the target. However, where elastic impacts are expected, the additional momentum transferred to the target by missile rebound should be included.

After it has been demonstrated that the missile will not penetrate the barrier, an equivalent static load concentrated at the impact area should then be determined, from which the structural response, in conjunction with other design loads, can be evaluated using conventional design methods. An acceptable procedure for such an analysis, where the impact is assumed to be plastic, is presented in a paper by Williamson and Alvy (Ref. 6). Other procedures may be used provided the results obtained are comparable to those referenced above.

Maximum allowable ductility ratios for steel and reinforced concrete barriers and other structural elements if used, in the above analysis, are given in Appendix A to this SRP section.

III. REVIEW PROCEDURES

The reviewer selects and emphasizes material from the review procedures described below as may be appropriate for a particular case.

1. For the prediction of local damage, the equations proposed by the applicant for estimation of missile penetration are reviewed in the following manner:

   a. For missile penetration in concrete, the reviewer verifies that the applicant has made a commitment to utilize empirical formulas such as the modified NDRC formula or valid test results. The reviewer also verifies that the applicant has made a commitment to provide sufficient barrier thickness to prevent perforation and to prevent spalling or scabbing when protection from spalling or scabbing is considered necessary.

b. For missile penetration in steel, the reviewer verifies that the applicant has made a commitment to utilize the more conservative of the BRL formula or the Stanford equations. If other equations are selected, the applicability and validity of such equations are reviewed to assure that the results are comparable to those obtained from the Stanford equations. If sufficient justification for the use of alternate equations is not provided, additional information is requested from the applicant at the first stage of the review.

c. For missile penetration in composite or multi-element barriers, the reviewer verifies that the applicant has made a commitment to utilize the criteria delineated in Section.II.1.c of this plan. If other criteria are proposed, the justification provided is reviewed to assure that such equations give results which are comparable to those referenced above.

2. For the prediction of overall damage and response of the barrier, the reviewer verifies that the applicant has made a commitment to utilize the criteria delineated in subsection II.2. of this SRP section. If other criteria are selected, the applicant's justification is reviewed to assure that the results obtained are at least as conservative as those delineated in subsection II.2. If sufficient justification is not provided, additional information is requested from the applicant at the first stage of the review.

IV. EVALUATION FINDINGS

The reviewer verifies that sufficient information has been provided to satisfy the requirements of this SRP section, and concludes that his evaluation is sufficiently complete and adequate to support the following type of conclusive statement to be included in the staff's Safety Evaluation Report:

The staff concludes that the barrier design is acceptable and meets the requirements of General Design Criteria 2 and 4 with respect to the capabilities of the structures, shields, and barriers to provide sufficient protection to equipment that must withstand the effects of natural phenomena (tornado missiles) and environmental effects including the effects of missiles, pipe whipping, and discharging fluids. This conclusion is based on the following:

The procedures utilized to determine the effects and loadings on seismic Category I structures and missile shields and barriers induced by design basis missiles selected for the plant are acceptable since these procedures provide a conservative basis for engineering design to assure that the structures or barriers are adequately resistant to and will withstand the effects of such forces.

The use of these procedures provides reasonable assurance that in the event of design basis missiles striking seismic Catefory I structures or other missile shields and barriers, the structural integrity of the structures, shields and barriers will not be impaired or degraded to an extent that will result in a loss of required protection. Seismic Category I systems and components protected by these structures are, therefore, adequately protected

against the effects of missiles and will perform their intended safety function, if needed. Conformance with these procedures is an acceptable basis for satisfying in part the requirements of General Design Criteria 2 and 4.

V. REFERENCES

1. 10 CFR Part 50, Appendix A, General Design Criterion 2, "Design Bases for Protection Against Natural Phenomena."

2. 10 CFR Part 50, Appendix A, General Design Criterion 4, "Environmental and Missile Design Bases."

3. R. P. Kennedy, "A Review of Procedures for the Analysis and Design of Concrete Structures to Resist Missile Impact Effects," Holmes and Narver, Inc., September, 1975.

4. W. B. Cottrell and A. W. Savolainen, "U.S. Reactor Containment Technology." ORNL-NSIC-5, Vol. 1, Chapter 6, Oak Ridge National Laboratory.

5. C.R. Russell, "Reactor Safeguards," MacMillan, New York, 1962.

6. R. F. Recht and T. W. Ipson, "Ballistic Perforation Dynamics," Journal of Applied Mechanics, Transactions of the ASME, Vol. 30, Series E, No. 3, Septemeber 1963.

7. R. A. Williamson and R. R. Alvy, "Impact Effect of Fragments Striking Structural Elements," Holmes and Narver, Inc., Revised November 1973.

8. Regulatory Guide 1.76, "Design Basis Tornado for Nuclear Power Plants."

TABLE 1

Minimum Acceptable Barrier Thickness Requirements
For Local Damage Prediction Against Tornado
Generated Missiles

Regions*	Concrete Strength (psi)	Wall Thickness (inches)	Roof Thickness (inches)
Region I	3000	23	18
	4000	20	16
	5000	18	14
Region II	3000	16	13
	4000	14	11
	5000	13	10
Region III	3000	<6	<6
	4000	<6	<6
	5000	<6	<6

*For definition of Region I, II, and III, refer to Regulatory Guide 1.76 (Ref. 8).

TABLE 2

Revised Tornado Missile Spectrum

Region 1

Missile	Dimensions (meters)	Mass (Kilograms)	Velocity[a] (meters per second)
Wood Plank	0.092 x 0.289 x 3.66	52	83
6-inch Schedule 40 Pipe	0.168 Diameter x 4.58	130	52
1-inch Steel Rod	0.0254 Diameter x 0.915	4	51
Utility Pole	0.343 Diameter x 10.68	510	55
12-inch Schedule 40 Pipe	0.32 Diameter x 4.58	340	47
Automobile	5 x 2 x 1.3	1810	59

[a]Velocities are horizontal velocities. For vertical velocities, 70 percent of the horizontal velocities are acceptable. For missile velocities in tornado regions other than Region I see SRP Section 3.5.1.4.

APPENDIX A

STANDARD REVIEW PLAN SECTION 3.5.3

PERMISSIBLE DUCTILITY RATIO
FOR OVERALL DAMAGE PREDICTION

I. INTRODUCTION

In the evaluation of overall response of reinforced concrete and steel structural elements (e.g., missile barriers, columns, slabs, etc.) subjected to impactive or impulsive loads, such as impacts due to missiles, assumption of nonlinear response (i.e., ductility ratios greater than unity) of the structural elements is generally acceptable provided that the intended safety functions of the structural elements and those of safety-related systems and components supported or protected by the elements are maintained. The following summarizes specific positions for review and acceptance of ductility ratios for reinforced concrete and steel structural elements subjected to impactive and impulsive loads.

II. SPECIFIC POSITIONS

1. Reinforced Concrete Members

The technical position of the regulatory staff with regard to permissible ductility ratios is stated in Regulatory Guide 1.142. Prior to publication of Revision 1 of Regulatory Guide 1.142, the staff position regarding ductility will be provided to applicants on a case-by-case basis.

2. Structural Steel Members

a. For tension due to flexure

$$\mu_d \leq 10.0$$

b. For columns with slenderness ratio (1/r) equal to or less than 20

$$\mu_d \leq 1.3$$

Where 1 = effective length of the member

r = the least radius of gyration

For columns with slenderness ratio greater than 20

$$\mu_d \leq 1.0$$

c. For members subjected to tension

$$\mu_d \leq 0.5 \frac{e_u}{e_y}$$

Where e_u = Ultimate strain

e_y = Yield strain